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Does modernization affect carbon dioxide emissions? A panel data analysis

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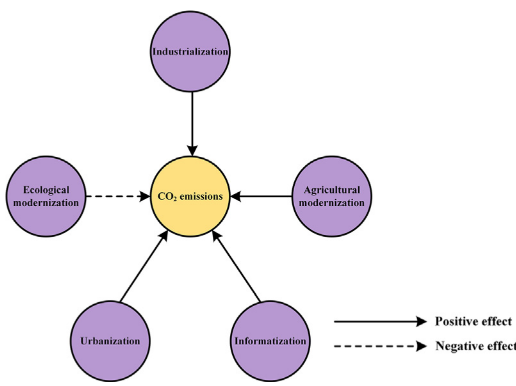
HIGHLIGHTS

- The impacts of modernization on carbon dioxide emissions were investigated.
- Five modernization indexes were developed based on a comprehensive indicator system.
- Industrialization and agricultural modernization increased carbon dioxide emissions.
- Informatization and urbanization had positive impacts on carbon dioxide emissions.
- Ecological modernization exerted a negative impact on carbon dioxide emissions.

GRAPHICAL ABSTRACT



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ABSTRACT

Modernization refers to the general trend of developmental progress that occurs within human societies. We now know that global warming, a result of carbon dioxide emissions, severely threatens the sustainability of human society. It is therefore of significant theoretical and practical implications that the scientific community more thoroughly investigate the impacts of modernization on CO_2 emissions. Surprisingly, only a limited number of studies have addressed this topic previously. As the world's largest developing economy and carbon emitter, China faces the dual challenge of peaking carbon emissions by 2030 while realizing basic modernization by 2035. With the purpose of identifying the implications of China's 2035 modernization goal for its 2030 emission peak goal, this study explored the effects of modernization on carbon dioxide emissions in China. Using a comprehensive indicator system, five modernization indexes—addressing industrialization, agricultural modernization, informatization, urbanization, and ecological modernization—were estimated, along with carbon dioxide emissions, for the period 1997–2016, for 30 Chinese provinces. Panel data modeling was then used to examine the impacts of the five modernization indexes on CO_2 emissions in China. The results demonstrate that industrialization, agricultural modernization, informatization, and urbanization exerted positive effects on CO_2 emissions during the study period, suggesting these aspects of modernization led to increased carbon dioxide emissions. A negative correlation between ecological modernization and carbon dioxide emission was identified, indicating that ecological modernization helped to abate CO_2 emissions. The findings emerging from this study hold significant implications for China's policy makers in promoting decarbonization, suggesting the

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utility of pursuing new-type industrialization, developing organic agriculture and eco-agriculture, popularizing electronic equipment with low power dissipation, building low-carbon cities, and promoting the ecology-oriented transformation of the modernization model.

1. Introduction

Human sustainable development is being threatened by global warming, which is mainly caused by carbon emissions. Human activities constitute the major driver of global carbon emissions. Modernization represents the general tendency towards progress within human civilizations; it consists of a range of processes including industrial upgrading, technological progress, and improvements in the environment and in living standards. Therefore, it is of great significance to investigate the effect of modernization on carbon emissions. As the largest developing economy in the world, China has not yet achieved full modernization, although it aims to realize basic modernization by 2035. With the purpose of identifying the implications of China's 2035 modernization goal for its 2030 emission peak goal, this study explored the effects of modernization on carbon dioxide emissions in China.

The identification of the anthropogenic factors that specifically affect carbon dioxide emissions is a task that has attracted considerable attention among academics (See Table 1). According to the classical IPAT theory, population, affluence, and technology constitute the three most prominent anthropogenic factors impacting on CO_2 emission. Economic growth is believed to have the largest impact on CO_2 emissions (Ma et al., 2019; Wang et al., 2018c). By performing a systematic review of >150 articles addressing economic growth and carbon dioxide emissions, Mardani et al. (2019) has concluded that economic growth increases carbon dioxide emissions and vice versa. This bidirectional causality between CO_2 emissions and economic growth was also identified by an empirical study on the "the Belt and Road" countries (Liu and Hao, 2018). Taking newly industrialized countries as example, Sharif Hossain (2011) identified economic growth as the Granger cause of CO_2 emissions. Recent empirical studies of Malaysia (Shahbaz et al., 2016) and China (S. Wang et al., 2016b) have identified economic growth as a dominating contributor to CO_2 emissions. Moreover, the environmental Kuznets curve (EKC) hypothesis, which holds that an inverted U-shaped relationship exists between carbon dioxide emission and economic growth, has popularly been examined in a range of previous studies (Acaravci and Ozturk, 2010; Begum et al., 2015), and it has been argued that well-designed policies can reduce carbon dioxide emissions without sacrificing human wellbeing (Schandl et al., 2016). Population has also been widely identified as a determinant of CO_2 emissions. Utilizing a cross-national panel data set, Liddle (2015) investigated the effect of population on CO_2 emissions, finding that population was positively correlated with CO_2 emissions. A similar conclusion was drawn in an empirical study of European countries (Martínez-Zarzoso et al., 2007). Additionally, demographic structure has also been demonstrated to affect carbon dioxide emission. For instance, Li and Zhou (2019) investigated the impact exerted by a series of demographic structure factors on CO_2 emissions in China, finding that average household size and the dependency ratio exerted negative impacts on carbon dioxide emissions. Other studies have addressed the nexus between technology and CO_2 emissions. S. Wang et al. (2016a) investigated the socioeconomic determinants of China's province-level carbon dioxide emission, with results suggesting that technological progress was beneficial to emission reduction. However, it has also been demonstrated that technological progress has not been able to completely offset the increase of carbon dioxide emissions due to population growth and rising affluence (Feng et al., 2009). This highlights the significance of technology transfer and technological innovation (Liang and Zhang, 2011). In addition to population, affluence, and technology, a range of other anthropogenic factors have also been shown to influence CO_2 emission, among which the impacts of urbanization prove particularly compelling. Empirical evidence from a number of cross-country analyses has suggested that urbanization positively correlates with CO_2 emissions (Al-mulali et al., 2013; Poumanyvong and Kaneko, 2010; Sadorsky, 2014), while other studies have found an inverted U-shaped relationship between urbanization and CO_2 emission (Martínez-Zarzoso and Maruotti, 2011). In the Chinese context, Wang et al. (2014) that investigated the link between carbon dioxide emissions and urbanization found that urbanization was positively associated with CO_2 emissions. Scholars have identified the transition to a more carbon-intensive lifestyles, a key effect of urbanization, as the mechanism driving increases in CO_2 emissions (Feng et al., 2012). A number of other additional factors have also been identified as increasing carbon dioxide emissions. Brizga et al. (2013), for example,

Table 1
Summary of existing empirical studies on the drivers of CO_2 emissions.

Study	Country/Territory	Period	Results
Population			
(Liddle, 2015)	26 OECD countries and 54 non-OECD countries	1971–2011	+
(Martínez-Zarzoso et al., 2007)	EU countries	1975–1999	+
Economic growth			
(Liu and Hao, 2018)	69 countries along the Belt and Road	1970–2013	Economic growth→CO_2
(Sharif Hossain, 2011)	Newly industrialized countries	1971–2007	Economic growth→CO_2
(Shahbaz et al., 2016)	Malaysia	1970–2011	Economic growth→CO_2
(Wang et al., 2016b)	China	1990–2012	Economic growth→CO_2
Technology			
(Wang et al., 2016a)	China	1995–2011	−
Urbanization			
(Al-mulali et al., 2013)	MENA countries	1980–2009	Urbanization→CO_2
(Poumanyvong and Kaneko, 2010)	99 countries	1975–2005	Urbanization→CO_2
(Wang et al., 2014)	China	1995–2011	Urbanization→CO_2
Energy structure			
(Brizga et al., 2013)	The former Soviet Union	1990–2010	+
(Shahbaz et al., 2013)	South Africa	1965–2008	Coal consumption→CO_2
FDI			
(Omri et al., 2014)	54 countries	1990–2011	FDI → CO_2
(Sarkodie and Strezov, 2019)	China, India, Iran, Indonesia and South Africa	1982–2016	+
Trade openness			
(Rafiq et al., 2016)	22 increasingly urbanized emerging economies	1980–2010	−
(Kasman and Duman, 2015)	New EU member and candidate countries	1992–2010	Trade openness→CO_2

Note: OECD: Organization for Economic Co-operation and Development, EU: European Union, MENA: Middle East and North Africa, → indicates Granger cause, + indicates positive correlation, − indicates negative correlation.

investigated the effect of energy structure on CO_2 emissions in the former Soviet Union, concluding that the impact of energy structure on CO_2 emissions varied across economic development stages, and that the percentage of fossil fuels positively correlated with such emissions during periods of economic recession. On the basis of a global panel data set, a study of the causal relationships between foreign direct investment (FDI) and CO_2 emissions identified a bidirectional causality between FDI and CO_2 emissions (Omri et al., 2014). Sarkodie and Strezov (2019) examined the effect of FDI on CO_2 emissions in developing economies, finding that FDI was positively associated with CO_2 emissions. Trade openness is another anthropogenic factor which exerts significant effect on CO_2 emission. On the basis of an empirical study on 22 increasingly urbanized emerging economies, Rafiq et al. (2016) found trade openness exerted a negative impact on CO_2 emissions; while another investigation provided evidence of a one-way causality running from trade openness to CO_2 emissions (Kasman and Duman, 2015). The impact of financial development on CO_2 emissions has also been investigated, and financial development has been found to negatively affect such emission (Khan et al., 2018). Urban areas, moreover, are believed to contribute to over 70% of all global CO_2 emissions (IEA, 2012); due to this, much academic attention has been directed towards the identifying the specific properties of urban areas that affect carbon dioxide emissions. Examples of such studies include that by Wang et al. (2015), who investigated the impact of urban development intensity on CO_2 emissions in five Chinese mega cities; and Li et al. (2018), who explored the impacts of a number of urban form factors—i.e., size, shape complexity, and compactness—on carbon dioxide emissions, highlighting the role that urban planning plays in carbon mitigation. Similarly, the effect of urban form on carbon dioxide emission was addressed in an investigation conducted by Wang et al. (2017), which also took transportation networks into consideration.

Despite a range of previous studies have investigated the anthropogenic determinants of carbon dioxide emissions, the explanatory variables most of these studies used, such as population and GDP, were bare-bones and prosaic. Modernization, a highly-integrated concept reflecting the general trend of developmental progress that occurs within human societies, is likely to be an important factor affecting carbon dioxide emissions. Nevertheless, the modernization-carbon nexus is poorly understood in previous studies, which leaves room for improving the analysis. Therefore, the novelty and contribution of this study is to explore the effect of modernization on carbon dioxide emissions, and thus advance the theoretical understanding of the anthropogenic driving force of carbon dioxide emissions. First, a comprehensive indicator system, which consisted of five sub-indexes—i.e., industrialization, agricultural modernization, informatization, urbanization, and ecological modernization—was developed in order to measure modernization levels of China's 30 province-level administrative regions[1] for the period 1997–2016. Carbon dioxide emissions in the 30 Chinese province-level administrative regions were then estimated utilizing the Intergovernmental Panel on Climate Change (IPCC) approach. The impacts of the five modernization indexes on carbon dioxide emission were finally examined using panel data models.

2. Materials and methods

2.1. Measuring modernization

Modernization is an open-ended and continuous process of transformation from the traditional to the modern in terms of economy, technology, lifestyle, communication, and civilization. In the context of the West, modernization theory attempts to explain the diffusion of Western styles of living, technological innovations and individualist types of communication, which are believed to be superior (Jinxia, 2010). In the context of China, modernization is regarded as a process of social revival linked to the transformation of the specific conditions of traditional societies, such as the paradigm shift of economy, communication, habitat, and axiology (Rosker, 2014).

In 2012, the report of the 18th National Congress of the Communist Party of China put forward "The synergetic development of industrialization, informatization, urbanization and agricultural modernization" and "Making great efforts to promote ecological progress" (Hu, 2012). In 2017, the report of the 19th National Congress of the Communist Party of China put forward "New industrialization, IT application, urbanization, and agricultural modernization go hand in hand" and "Speeding up reform of the system for developing an ecological civilization, and building a beautiful China" (Xi, 2017). Therefore, a comprehensive indicator system, which consisted of five sub-indexes (i.e., industrialization, agricultural modernization, informatization, urbanization, and ecological modernization), was developed to evaluate the modernization levels for China's provinces. Each sub-index consisted of six basic indicators, which reflected both the definition of modernization and data availability. Table 2 shows the detailed index system.

Before calculating the modernization index, the effects of positive-negative orientation, dimension, and magnitude needed to be eliminated by means of the implementation of a process of standardization. The range method was used to standardize the data and ensure that values fell within [0, 1]. The formulas for the range method are shown in Eqs. (1) and (2).

$$\text{Positive indicator}: r_{ij} = \frac{X_{ij} - min(X_j)}{max(X_j) - min(X_j)} \tag{1}$$

$$\text{Negative indicator}: r_{ij} = \frac{max(X_j) - X_{ij}}{max(X_j) - min(X_j)} \tag{2}$$

where r denotes the standardized value; X refers to the raw value; min( ) and max( ) denote the minimum and maximum of the raw values, respectively; i and j denote year and indicator, respectively.

After standardizing the data, the weight of each indicator needs to be determined. The entropy method is an objective method that is used to determine weights (Shemshadi et al., 2011), particularly in situations when reliable subjective weights aren't able to be obtained (Deng et al., 2000)—as was the case in this study. The mathematical models for the entropy method are shown in Eqs. (3)–(6). The weight of each indicator is displayed in Table 1.

$$\text{The percentage of the indicator } j \text{ in year } i: X_{ij} = \frac{r_{ij}}{\sum_{i=1}^{n} r_{ij}} \tag{3}$$

$$\text{Information entropy}: e_j = -\frac{1}{\ln n}\sum_{i=1}^{n} X_{ij} \times \ln X_{ij} \ (0 \le e_j \le 1) \tag{4}$$

$$\text{Entropy redundancy}: f_j = 1 - e_j \tag{5}$$

$$\text{Weight of the indicator}: w_j = \frac{f_j}{\sum_{j=1}^{m} f_i} \tag{6}$$

Combining the standardized value with the weight of each indicator, five indexes reflecting the modernization levels of China's 30 province-level administrative regions were calculated for the period 1997–2016, using Eq. (7).

$$\text{Evaluation of a single indicator}: Y_{ij} = w_j \times r_{ij} \tag{7}$$

Fig. 1 shows the statistical characteristics of the five modernization indexes for Chinese provinces for the period 1997–2016, in the form of a series of box charts. The top and bottom of each box respectively represent the 75th and 25th centiles. IND was found to be mainly dispersed between 0 and 0.05, and was concentrated at 0.025. AGR was evenly distributed from 0 to 0.1. INFOR was distributed from 0 to 0.15,

[1] Due to the data limitations, Taiwan, Tibet, Hong Kong, and Macao were not included in the sample.

Table 2
Index system of modernization.

Sub-index	Indicator	Description	Weight (%)
Industrialization	Industrialization rate	The share of industrial added value to GDP (%)	0.79
	Industrial employment rate	The share of industrial employment to total employment (%)	2.34
	Ratio of profits to cost	The ratio of total profit to total cost (%)	0.64
	Return on assets	The ratio of total profit to total assets (%)	1.76
	Current assets turnover	The ratio of net revenue from principal business to average total current assets (%)	1.74
	Technological innovation	Number of patents granted per 1000 person (piece)	15.04
Agricultural modernization	Agricultural mechanization level	Agricultural machinery power per unit of sown area (W/m^2)	3.17
	Effective irrigation rate	The share of effective irrigation area to total sown area (%)	2.38
	Chemical fertilizer consumption per unit of land	Total chemical fertilizer consumption divided by total sown area (kg/m^2)	2.42
	Pesticide consumption per unit of land	Total pesticide consumption divided by total sown area (kg/hm^2)	4.76
	Grain yield per unit of land	Total grain yield divided by sown area of grain crops (kg/m^2)	1.53
	Grain yield per capita	Total grain yield divided by total population (kg/person)	2.84
Informatization	Telecommunication service index	The ratio of business volume of telecommunication services to GDP (%)	3.11
	Popularizing rate of fixed-line telephone	The number of fixed-line telephone subscribers per 100 person	2.35
	Popularizing rate of cellphone	The number of cellphone subscribers per 100 person	5.30
	Popularizing rate of computer	The number of computer ownership per 100 households (set)	4.46
	Informatization facilities	The length of long-distance optical cable lines per capita (m/person)	7.12
	Informatization human capital	The share of college student to total population (%)	3.46
Urbanization	Population urbanization rate	The percentage of urban population (%)	2.25
	Land urbanization rate	The share of built-up area to total area (%)	12.71
	Urban road	The area of paved road per capita (m^2/person)	2.47
	Urban public transport	The quantity of public transport vehicles per 10,000 person (vehicle/10,000 person)	2.08
	Urban landscaping	Public green area per capita (m^2/person)	1.88
	Urban sanitation	The number of special vehicles for urban sanitation per 10,000 person (vehicle/10,000 person)	7.56
Ecological modernization	Waste gas emission	Per capita industrial waste gas emission (m^3/person)	0.14
	Waste gas treatment	The share of industrial SO_2 removed to total industrial SO_2 output (%)	2.84
	Waste water discharge	Industrial wastewater discharge per capita (t/person)	0.26
	Waste water treatment	The share of industrial wastewater reaching discharge standard to total industrial wastewater discharge (%)	0.80
	Solid waste output	Industrial solid waste output per capita (t/person)	0.13
	Solid waste treatment	The share of comprehensively-utilized industrial solid waste to total industrial solid waste output (%)	1.67

and was concentrated at 0.075. URBAN was revealed to mainly disperse from 0 to 0.1, and to be highly concentrated at 0.025. The distribution of ECO was generally even, mainly dispersing from 0 to 0.05.

2.2. Measuring carbon dioxide emissions

China does not publish official carbon dioxide emission data; because of this, China's carbon dioxide emission data is generally obtained by way of estimation (Shan et al., 2018). The Intergovernmental Panel on Climate Change (IPCC) emissions accounting approach (IPCC, 2006) can be used to measure anthropogenic emissions by means of consideration of the resident activities and domestic production that occur within a given region's boundaries (Kennedy et al., 2010). This is a reliable and widely used carbon dioxide emissions estimation technique, employed here in relation to province-level administrative regions in China, using Eq. (8).

$$CO_{2i} = \sum_{i=1}^{7} (E_i \times F_i) \quad (8)$$

where CO_2 is carbon dioxide emissions; E refers to the consumption of primary energy; F represents the CO_2 emission factor; i refers to the categories of fossil fuels.

Fig. 2 displays China's province-level CO_2 emissions per capita from 1997 to 2016. The results demonstrate that the carbon dioxide

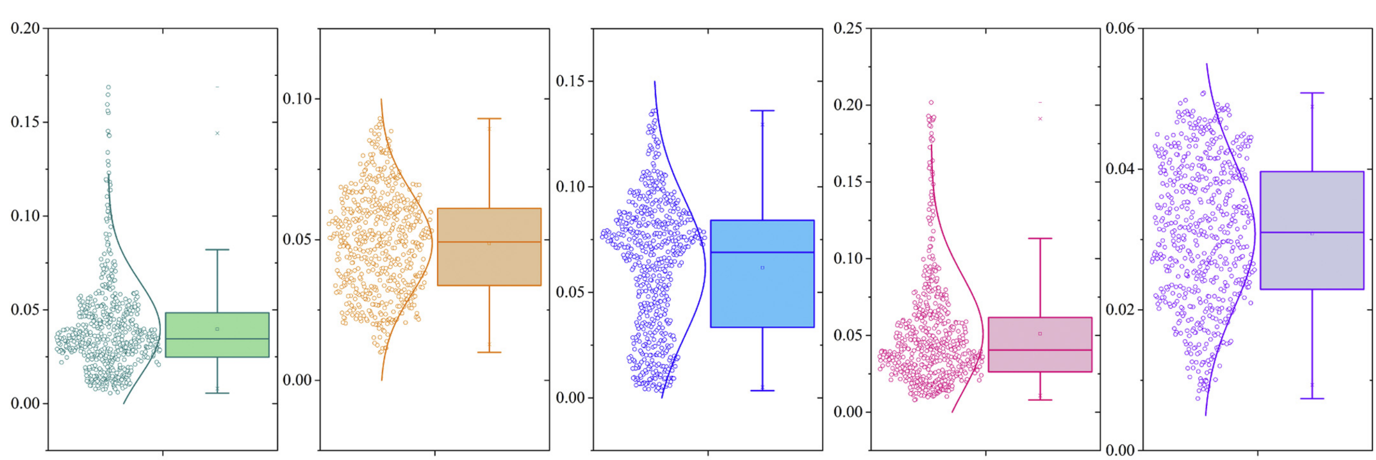

Fig. 1. Box charts of the five modernization indexes with scatter plot and distribution overlays.

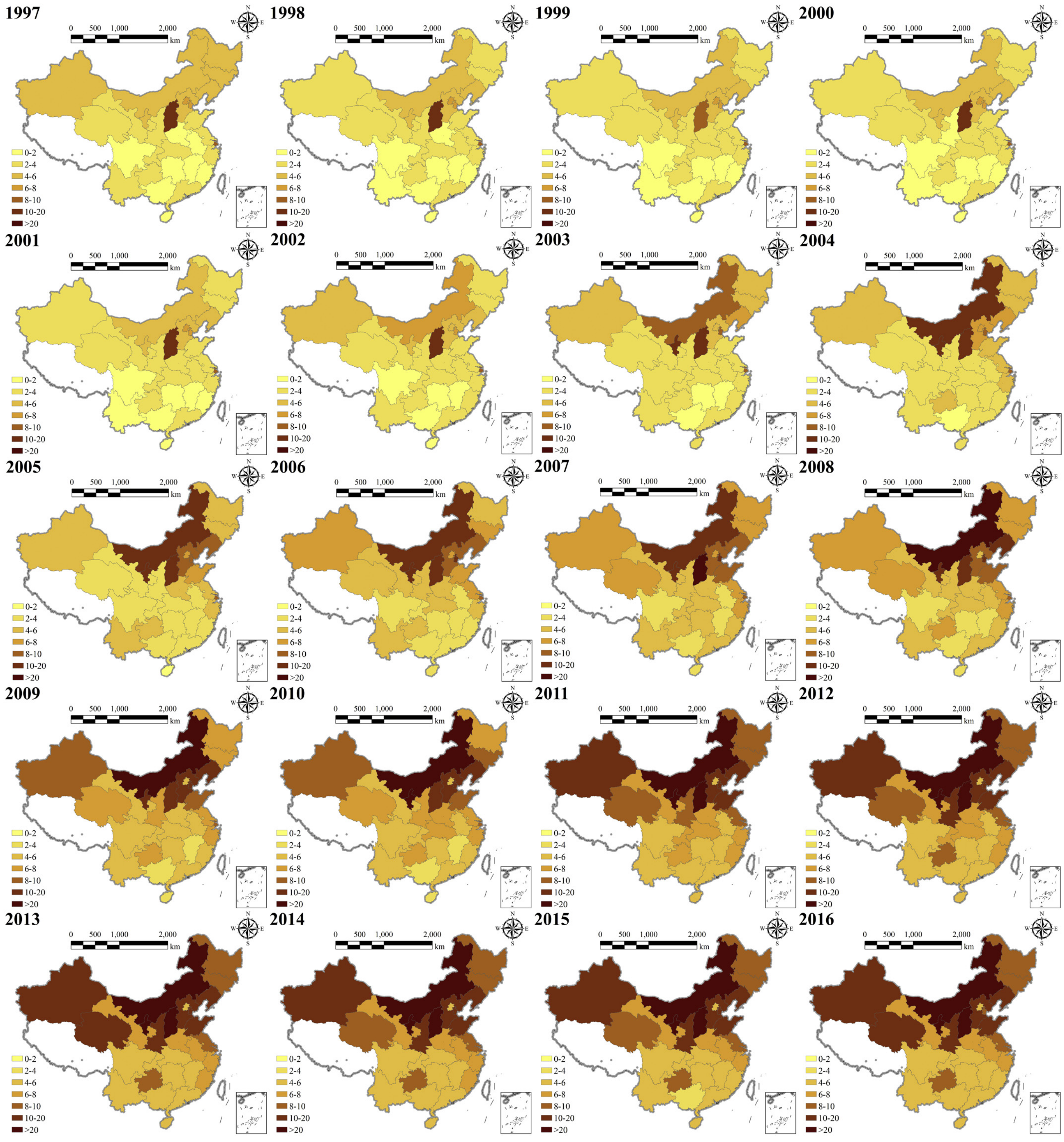

Fig. 2. Carbon dioxide emissions per capita in China's provinces, 1997–2016 (t).

emissions per capita of China's provinces experienced evident growth during the study period, providing evidence of a transition to a more energy-dependent development model and a more carbon-intensive lifestyle. Moreover, clear spatial differences existed in the carbon dioxide emissions per capita of China's provinces. Generally, provinces in northern China had higher carbon dioxide emissions per capita than provinces in southern China, a finding which reflects the fact that the former are rich in fossil energies and require more intensive heating during the winter.

2.3. Panel data modeling

The relationship between modernization and CO_2 emissions in China were estimated using panel data modeling. Prior to conducting parameter estimations in panel data modeling, a number of pre-tests need to be performed, including the multicollinearity test and the Hausman test. Multicollinearity constitutes one of the methodological problems that must be confronted in multiple linear regression modeling, if the explanatory variables are to be able to describe the dependent

variable (Spanos and McGuirk, 2002). Severe multicollinearity refers to the existence of considerable correlation between the explanatory variables, which is likely to make the least squares estimates largely pointless (Kovacs et al., 2005). Panel data modeling generally employs two typical estimators—random-effects estimators and fixed- effects estimators—and the appropriateness of either of these two methods is usually identified using a Hausman test (Hausman, 1978). In the random-effects method, unobservable and time-invariant factors for each observation unit are treated as part of the disturbances, thereby assuming that their correlation with the regressors is zero: this is the null hypothesis of the Hausman test (Baltagi et al., 2003). If the Hausman test result rejects the null hypothesis, the random-effects estimator confers the advantage of greater efficiency over the fixed-effects estimator. Otherwise, the fixed-effects estimator should be applied.

Panel data modeling is a widely-used technique in empirical studies, due to the evident advantages it offers over conventional cross-sectional or time series modeling methods. The purpose of this study was to investigate the effects of the five modernization indexes on CO_2 emissions in China. The panel data modeling technique was considered an appropriate approach to achieve the above goal, and was employed taking the period 1997–2016 into account. The model can be specified as follows:

$$CO_{2it} = a_0 + a_1 IND_{it} + a_2 AGR_{it} + a_3 INFOR_{it} + a_4 URBAN_{it} + a_5 ECO_{it} + \varepsilon_{it} \tag{9}$$

where CO_2 denotes carbon dioxide emissions, IND denotes industrialization, AGR refers to agricultural modernization, INFOR refers to informatization, URBAN represents urbanization, and ECO represents ecological modernization; a_0 is the constant term, and ε is the random error; t and i denote year and province, respectively.

2.4. Data acquisition

The reason why 1997–2016 was selected as the time interval of this study included two aspects. On the one hand, the latest energy consumption data was for the year 2016 (obtained from China Energy Statistical Yearbook 2017). On the other hand, Chongqing had not become a municipality until 1997, which meant Chongqing's data before 1997 and Chongqing's data after 1997 was incomparable. Moreover, there were also two reasons why this study was conducted at China's province-level. For one thing, China only publishes official energy consumption data for its provincial-level administrative region, which means carbon dioxide emission accounting is feasible only at China's province-level. For another, modernization is a highly-integrated concept, due to which this study developed a comprehensive index system consisting of 30 basic indicators, and these data are available only at China's province-level.

Data for the 30 basic indicators making up the index system measuring modernization were collected from the China Statistical Yearbook (1998–2017), the China Rural Statistical Yearbook (1998–2017), the China Statistical Yearbook on Environment (1998–2017), and the China Compendium of Statistics 1949–2008. The energy consumption data were obtained from the China Energy Statistical Yearbook (1998–2017), and the population data were collected from the China Statistical Yearbook (1998–2017).

3. Results and interpretation

3.1. Variations in China's province-level modernization indexes

Fig. 3 shows the variation trajectories of the five modernization indexes in China's provinces from 1997 to 2016. The industrialization levels of China's provinces experienced remarkable growth in the past last twenty years—this trend is especially clear in Shanghai, Beijing, Zhejiang, Jiangsu, Guangdong, and Tianjin, which have become China's most developed provinces. In contrast, Hainan maintained the lowest industrialization index value during the whole period. The trajectories for AGR were found be to be smooth, indicating agricultural modernization improve significantly in Chinese provinces during the period 1997–2016. While Beijing's agricultural modernization index was the highest in 1997, by 2016, Hainan had taken over as having highest value. The agricultural modernization index value of Guizhou was the lowest of all provinces during the entire period. The INFOR curves were quite steep, demonstrating China's considerable achievements made in terms of informatization. Beijing, Shanghai, and Guangdong constitute the three province-level administrative regions with the highest informatization levels; they are in turn located in China's three major urban agglomerations, namely, the Beijing-Tianjin-Hebei Region, the Yangtze River Delta, and the Pearl River Delta. Moreover, we found that Henan, a province representative of Central China more generally, had the lowest informatization level during the last twenty years. An evident gap exists between the URBAN trajectories of China's three municipalities (i.e., Beijing, Tianjin, and Shanghai) and the URBAN trajectories of the rest of the provincial administrative units, indicating significant regional differences in urbanization in China. Guizhou had the lowest urbanization index. Although the trajectories of ECO were shown to zigzag, ecological modernization was found to follow an overall upward trend. In the last twenty years, Anhui was revealed to be the province with the highest ecological modernization index score, while Qinghai had the lowest.

3.2. Results of panel data modeling

3.2.1. Results of pre-tests

Two pre-tests—a multicollinearity tests and a Hausman test—were performed before running the panel data models. Table 3 reviews Pearson's correlation coefficients for the five modernization indexes, the explanatory variables in this study. No high correlations were found to exist among the independent variables, suggesting that they didn't suffer from the problem of severe multicollinearity. For this reason, panel data modeling was able to be conducted.

Hausman tests were performed to identify suitable regression types for each model, including the random effects model and the fixed effects model. The null hypothesis of the Hausman test is that the random effects model is more suitable. As shown in Table 4, the P values of Model 1 and Model 3 were greater than the critical value at the 5% significance level, without rejecting the null hypothesis of random effects, while the P values of Model 2, Model 4, and Model 5 were less than the critical value at the significance of 5% level, rejecting the null hypothesis of random effects. According to the above results, Model 1 and Model 3 were established based on random effects models, while Model 2, Model 4, and Model 5 were developed based on fixed effects models.

3.2.2. The estimation results of the panel data models

In order to test the robustness of the panel data modeling results, we used the stepwise regression technique in this study. The five modernization indexes were sequentially incorporated into the CO_2-modernization model, and five panel data models were generated. The estimation results of these models are shown in Table 5. The coefficients of IND in all the five models were found to be significantly positive, indicating a positive correlation between IND and CO_2 emissions. In terms of both output values and employment, industrialization is a process wherein the share of secondary industry increases while that of primary industry decreases. This change constitutes the fundamental driving force in economic development. Since manufacturing industry is more energy-intensive than agriculture and handicrafts, increases in the industrialization level inevitably leads to rising carbon dioxide emissions (Li and Lin, 2015). As a result, on the one hand, industrialization leads to greater energy consumption in the manufacturing process, which generates a greater volume of direct carbon dioxide emissions; on the other hand, though, industrialization can stimulate the demand for

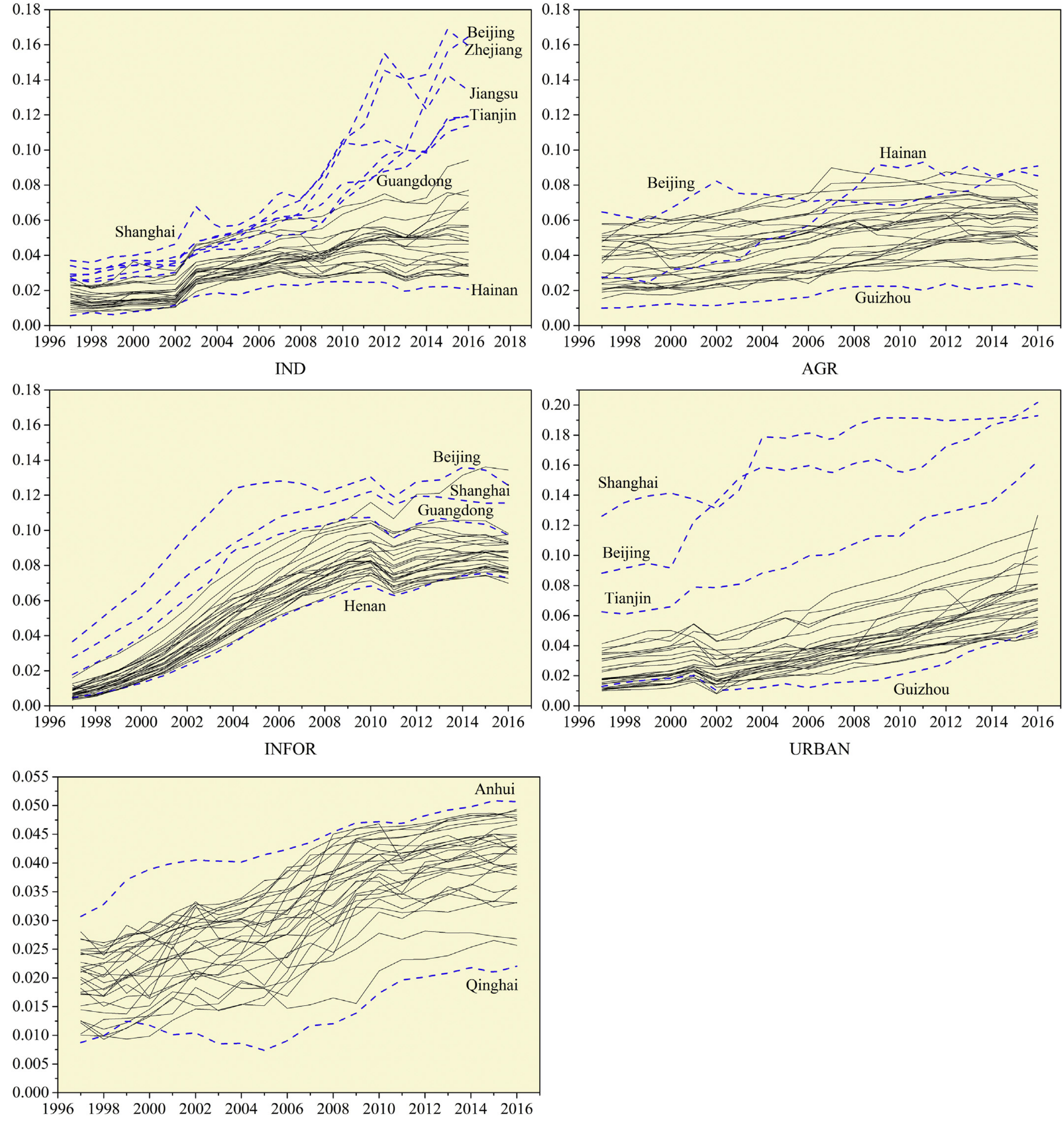

Fig. 3. Variation trajectories of the five modernization indexes in China's provinces, 1997–2016.

Table 3
The Pearson's correlation coefficients of the explanatory variables.

	IND	AGR	INFOR	URBAN	ECO
IND	1				
AGR	0.585***	1			
INFOR	0.670***	0.547***	1		
URBAN	0.668***	0.599***	0.650***	1	
ECO	0.632***	0.574***	0.624***	0.507***	1

*** Indicates significant at 1% level.

Table 4
The results of Hausman tests.

	Chi-Sq statistic	*P* value	Type of regression model
Model 1	3.34	0.0677	Random effects
Model 2	37.40	0.0000	Fixed effects
Model 3	4.03	0.2588	Random effects
Model 4	11.36	0.0228	Fixed effects
Model 5	17.79	0.0032	Fixed effects

Table 5
The estimation results of panel data models.

	Model 1	Model 2	Model 3	Model 4	Model 5
IND	70.62***	52.68***	47.52***	24.19***	18.23***
	(6.602)	(6.779)	(7.374)	(7.671)	(7.609)
AGR		196.9***	67.05***	53.37***	32.33**
		(13.52)	(16.42)	(16.52)	(16.81)
INFOR			75.32***	52.32***	36.33***
			(6.897)	(7.179)	(7.815)
URBAN				76.26***	58.25***
				(9.453)	(10.03)
ECO					−133.8***
					(28.28)
Constant	3.758***	−3.748***	−0.389*	−1.270**	−2.260***
	(0.803)	(0.570)	(0.962)	(0.576)	(0.603)
R-squared	0.843	0.860	0.871	0.890	0.897

*** Indicates significant at 1% level.
** Indicates significant at 5% level.
* Indicates significant at 10% level.

logistics, and thus increase carbon dioxide emissions even further by means of indirect transportation-related emissions.

AGR was demonstrated to have a positive relationship with carbon dioxide emissions, suggesting that agricultural modernization helped to increase carbon dioxide emissions. In the context of traditional agriculture, livelihoods are highly dependent on natural resources, and the effects of human action on agricultural production are limited (Kansanga et al., 2018). Agricultural modernization denotes a transition from traditional agriculture to modern agriculture, which is characterized by the adoption of modern agricultural technologies; the mechanization of farming increases cultivable areas and land-use intensity. The popularization of agricultural machinery in ploughing, typified by the use of tractors, brings about increased fuel consumption and consequent increases in carbon dioxide emissions. In addition, agricultural modernization stimulates the demand for chemical fertilizers and pesticide, the production of which is highly dependent on energy consumption—this also results in increased carbon dioxide emissions.

INFOR was demonstrated to have a positive relationship with carbon dioxide emissions, suggesting that informatization led to the increases in CO_2 emissions during the period studied. Since the foundation of informatization lies in the utilization of information and communication technology, which is highly dependent on computer and other electronic facilities, informatization consumes an enormous amount of electricity. Given the fact that the share of renewable energies is still limited in China, the generation of electricity remains highly dependent on fossil energies, which leads to the emission of considerable volumes of carbon dioxide. The higher the informatization level is, the greater carbon dioxide emissions are.

Our results show that URBAN was positively correlated with carbon dioxide emissions, which is consistent with both our expectations and the results of previous studies (Behera and Dash, 2017; Ponce de Leon Barido and Marshall, 2014; Y. Wang et al., 2016; Zhang and Lin, 2012). Urbanization is a process whereby rural populations become urban populations and farmland is converted to urban areas, which results in evident changes in lifestyle and in land use. Urban lifestyles are believed to be more energy-intensive than rural lifestyles, and increases in the urban population increases demand for urban infrastructure (including transportation networks and buildings), which is believed to contribute significantly to growth in carbon dioxide emissions. Moreover, landscape changes resulting from urbanization reduce vegetation, which plays a significant role in carbon sequestration.

This study identified a negative correlation between ECO and carbon dioxide emissions, indicating that ecological modernization was conducive to reducing CO_2 emissions. Ecological modernization refers to various social practices aiming to integrate concerns for the environment with human development and to reform the economic system along ecological lines (Hermanns, 2015). The development-emission nexus has been widely examined, and a sustainability dilemma seems to exist: that is, while development inevitably leads to greater carbon dioxide emissions, emission reduction cannot be realized without sacrificing development. Ecological modernization thus emerges as a possible way forward in mitigating emissions without, or with only minimal, impact on development.

4. Conclusion and discussion

Modernization refers to the general trend of developmental progress that occurs within human societies, through industrial upgrading, technological progress, and improvements in the environment and living standards. As the world's largest developing economy, China still faces the goal of achieving modernization. The Chinese government aims to successfully achieve basic modernization by 2035. China is, due to its rapid economic development, also the largest carbon emitter in the world; it thus faces a second great challenge in the form of achieving carbon emission reductions, and the Chinese government has as a result committed to peaking carbon emission by 2030. It is of great significance that the scientific community investigate the implications of China's 2035 modernization goal for its 2030 emission peak goal. Previous studies have shown that a range of anthropogenic factors exert significant impacts on carbon dioxide emission, including population, economic growth, technology, urbanization, energy mix, FDI, and trade openness. Despite these insights, the effect of modernization on CO_2 emission has been seldom addressed in the scientific literature to date. With the aim of filling this gap, this study investigated the impacts of modernization on carbon dioxide emissions in China. We first calculated the modernization levels of China's provincial administrative units for the period 1997–2016 based on a comprehensive indicator system, which consisted of five sub-indexes, i.e., industrialization, agricultural modernization, informatization, urbanization, and ecological modernization. We then estimated the carbon dioxide emissions levels of China's provinces using the IPCC method. A panel data modeling technique was then employed to identify the impacts of each of the five modernization indexes on carbon dioxide emissions. Prior to running the panel data models, multicollinearity tests and Hausman tests were performed.

The results of the multicollinearity tests suggested that the explanatory variables did not suffer from severe multicollinearity; given this, panel data modeling could be conducted. Hausman tests were performed to choose the appropriate regression types from the random-effects estimator and the fixed-effects estimator. The results of the parameter estimation demonstrated that industrialization, agricultural modernization, informatization, and urbanization were positively associated with CO_2 emissions, while there was a negative correlation between ecological modernization and CO_2 emissions. Given that the share of secondary industry, which consists of more energy-intensive sectors, increases during processes of industrialization, it follows logically that industrialization leads to increases in CO_2 emissions. Due to differences between traditional agriculture and modern agriculture (most significantly through increases in the mechanization level, chemical fertilizer use, and pesticide use, which all stimulate the demand for energy), agricultural modernization also increases carbon dioxide emissions. Informatization is highly dependent on computers and other electronic facilities, which cannot operate without electricity. In China, the majority of electricity is generated by the combustion of fossil energies, emitting considerable volume of carbon dioxide. Given this link, improvements in the informatization level lead to increases in carbon dioxide emissions. Urbanization witnesses the transformation of rural populations into urban populations. Since urban lifestyles are more energy-intensive than rural lifestyles, the process of urbanization contributes significantly to the growth of carbon dioxide emissions. In addition, urbanization also brings about evident changes in land use—i.e., reducing farmland and increasing urban area—which in turn decreases vegetation and consequently reduces carbon absorption. Finally,

ecological modernization refers to a development idea that integrates concerns for the environment with human development, advocating reforms to the economic system that proceed along ecological lines. Our findings indicates that ecological modernization is beneficial to reducing carbon dioxide emissions, and that it therefore constitutes an effective way to mitigate emissions.

The findings obtained from this study hold significant policy implications for China's decision makers. First of all, our results indicate that new-type industrialization—characterized by less resource consumption and environmental pollution, and a commitment to the development of high-tech and high-efficiency industries—should be pursued rather than conventional industrialization. The Chinese government should accelerate the transformation of China's development model accordingly, realizing the decoupling of industrialization from resources and environment. Secondly, agricultural modernization should be redirected towards the development of organic agriculture and eco-agriculture, building an agro-ecological system with high yield and low consumption. The use of chemical fertilizer and pesticides should be controlled in order to mitigate carbon dioxide emissions. Thirdly, electronic equipment with low-power dissipation should be popularized, with the purpose of saving energy and reducing CO_2 emissions. Moreover, energy-intensive informatization infrastructures, such as electronic data centers, should be located in areas with abundant sunshine and low temperatures, in order to take advantage of photovoltaic energy and to save energy by means of heat dissipation. Fourthly, drastic urbanization should be avoided and moderate urbanization instead promoted. Building low-carbon cities is an effective way to offset the growth of CO_2 emissions deriving from urbanization. The government should also work to raise public awareness of energy conservation and emission reduction strategies, advocating low-carbon lifestyles. Last but not least, the Chinese government should promote the ecology-oriented transformation of the modernization model, aiming to build an ecological civilization. Specifically, efforts to develop a system for promoting coordinated economic and ecological advancement should be accelerated.

In spite of yielding informative findings, this study has some limitations (Wang et al., 2018a, 2018b). First of all, this study used a same set of emission coefficients to estimate carbon emissions for Chinese provinces, which is inconsistent with the reality. In order to better address the impact of modernization on carbon emissions, more accurate carbon emission accounting is expected in future studies. Moreover, what this study employed is conventional econometric method, which doesn't take Tobler's first law of geography into account, that is, everything is related to everything else, but near things are more related to each other (Tobler, 1970). Assuming the parameter estimation of a certain spatial unit is affected by that of other spatial units may be more in line with the reality (Li et al., 2019). Therefore, regression models addressing the issue of spatial autocorrelation, such as geographically weighted regression (GWR), are expected to more fully investigate the effect of modernization on carbon emissions. Last but not the least, since the aggregated statistics constitute the data source of this study, the modifiable areal unit problem (MAUP), which is a source of statistical bias, may affect the results of statistical hypothesis tests.

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